TUAM 2.2

COMPLEXITY EVALUATION FOR THE IMPLEMENTATION OF A PRE-FFT EQUALIZER IN AN OFDM RECEIVER

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ABSTRACT

A Pre-FFT Equalizer (PFE) has been shown to offer a significant throughput efficiency improvement when applied to an OFDM receiver. In this paper, the required computational complexity to implement such an equalizer is evaluated assuming the LMS adaptation algorithm. The paper concludes by discussing the potential efficiency and complexity trade-offs that can be achieved when applying this technology to standards such as Hiperlan /2, IEEE P802.11a and DVB-T.

INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a robust modulation technique that has been selected for a number of radio communications standards, including DVB-T [1], HIPERLAN /2 [2] and IEEE P802.11a [3]. These standards are expected to have significant impact in the consumer electronics market, particularly in areas such as digital video distribution and home wireless networking.

A novel combined OFDM-Equalization technique [4], incorporating a pre-FFT Equalizer (PFE) has recently been developed. This technique has been shown to offer an improvement in bandwidth efficiency over the conventional OFDM technique [5]. However, this improvement comes at the expense of additional receiver complexity. The performance of the PFE has already been investigated under radio impairments such as additive noise and mobile channel conditions [5].

This paper investigates the complexity of the PFE assuming training via the LMS adaptation algorithm. The required MIPS (Millions of Instructions Per Second) count for PFE implementation in HIPERLAN/2, IEEE 802.11 and DVB-T is evaluated. The results of this study will be used to determine the additional complexity cost of applying combined OFDM-equalization in comparison to conventional OFDM. This additional complexity cost is considered alongside the efficiency gains offered by combined OFDM-equalization. Possible methods to improve the trade-off between efficiency and cost are also investigated.

LMS ANALYSIS

The following complexity analysis is performed based on an adaptive PFE using LMS adaptation for equalizer training. The number of MIPS also includes implementation of the equalizing filter. Unlike the Decision Feedback Equalizer (DFE), the PFE uses a variation on the LMS algorithm for decision directed adaptation during the data payload.

LMS-Training: A standard LMS algorithm is used by the PFE during the training mode:

$$c(j,(n+1)) = c(j,n) + \Delta y(n-j)\varepsilon(n)^* \qquad (1)$$

Where $c(.)$ represents the tap coefficient vector, $y(.)$ the received signal and $\varepsilon(.)$ the equalizer output error. j and n index the tap-coefficient and time sample respectively.

The required number of complex multiplications per clock cycle assuming LMS Training are given by:

$$N_{CMULT-T} = 2(J_1 + J_2) \qquad (2)$$

where J_1 and J_2 denote the number of taps in the feedforward and feedback filter sections respectively.

The required number of complex additions per clock cycle assuming LMS training are given by:

$$N_{CADD-T} = (J_1 + J_2) \qquad (3)$$

LMS Decision Directed Tracking: Decision Directed adaptation of the PFE employs a variation on the conventional LMS algorithm taking the general form [4]:

$$c(j,(l+1)) = c(j,l) + \sum_{n=0}^{N-1} \Delta y(n-j)\varepsilon(n)^* \qquad (4)$$

Where l indexes the OFDM symbol and N represents the FFT size. This modified adaptation algorithm generates one new coefficient vector per OFDM symbol, instead of per transmission symbol. Thus, the coefficient vector must be updated at *1/N* times the symbol rate during training, with each update requiring N times more operations per update. The summation term in equation 4 is implemented by reproducing both the equalizing filter functionality and the LMS-Training algorithm within the decision directed LMS coefficient calculation process. The required computation for decision directed LMS adaptation is thus equal to the sum of the filter and LMS-training computation requirements.

The required number of complex multiplications per clock cycle for decision directed adaptation is:

$$N_{CMULT-DD} = 3(J_1 + J_2) \tag{5}$$

The required number of complex additions per clock cycle for decision directed adaptation is given by:

$$N_{CADD-DD} = 2(J_1 + J_2) \tag{6}$$

MIPS COUNT

A complex addition can be implemented as two real additions. A complex multiplication can be implemented as three real multiplications plus five real additions [6]. Thus, the total number of instructions per clock cycle required to implement PFE training is given by:

$$N_{OPS-T} = 2_{NCADD-T} + 8N_{CMULT-T} \tag{7}$$

$$N_{OPS-DD} = 2_{NCADD-DD} + 8N_{CMULT-DD} \tag{8}$$

RESULTS & CONCLUSIONS

Table 1 presents the relevant parameters of the three standards considered in this paper. Using these parameters in conjunction with equations 7 and 8, an initial estimate for the required number of MIPS for a given application can be determined.

	HIPERLAN/2 / IEEE P802.11a	DVB-T 2k Mode
Tx Rate	20MHz	9MHz
Max. Delay Spread	250ns RMS	50µs
OFDM Symbol Period	3.2• s	224µs
Guard Interval Fraction	1/4 or 1/8	1/4, 1/8, 1/16 or 1/32

Table 1: System Parameters

HIPERLAN/2: Figure 1 shows the computational requirements versus maximum delay spread capability for a HIPERLAN/2 or IEEE P802.11a PFE as a function of the number of equalizer taps. A 9-tap PFE offers an efficiency increase of approximately 9% (since the guard interval can be reduced from 800ns to 400ns). This is equivalent to an increase of up to 4.8Mbits/s in raw data throughput. This is achieved at the cost of 5,040 additional MIPS or 2,880 additional MIPS if no decision directed channel tracking is employed. The latter case is a realistic option since the length of a Wireless LAN data packet is considerably shorter than the coherence time of the expected channel. This complexity offers a moderate increase in efficiency for a considerable increase in complexity. More appropriate adaptation methods such as 'single shot' calculations may offer reduced complexity with comparable, or even superior, performance. Such techniques are expected to achieve a more desirable PFE cost/performance trade-off for such systems.

DVB-T 2k mode: This system requires considerably more computational capability to achieve any useful PFE implementation. Although the lower transmission rate of DVB-T requires only 9/20 of the MIPS in comparison to HIPERLAN/2, the longer delay spreads in the outdoor broadcast channel result in the need for many more filter taps. Decision Directed channel tracking will almost certainly be required in this application. 64,512 MIPS are required to achieve a 9% efficiency improvement. This represents a very poor complexity/efficiency tradeoff. The application of the PFE to DVB-T 2k offers the potential to move from a multi-frequency network to a single frequency network. In this case, a potential seven-fold increase in spectral efficiency can be achieved. However the complexity using the LMS algorithm requires in excess of 50,000 MIPS. Clearly, if the PFE is to be applied in DVB-T, a far lower complexity approach must be found. Methods to exploit the sparse characteristics of the broadcast channel should be considered.

REFERENCES

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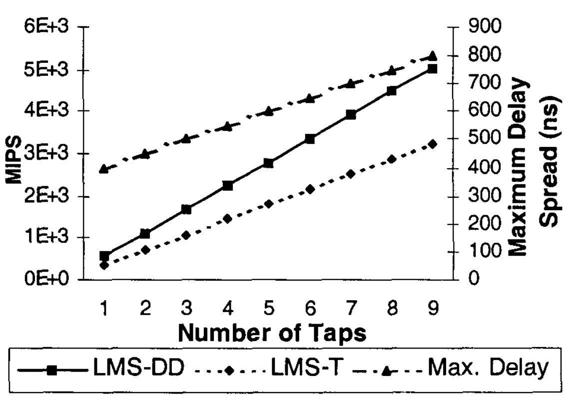

Figure 1. Complexity and Maximum Delay Spread of a PFE for HIPERLAN/2.